

AGROCLIMATOLOGY

Modeling Diurnal Canopy Temperature Dynamics Using One-Time-of-Day Measurements and a Reference Temperature Curve

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ABSTRACT

The application of the temperature–time threshold (TTT) method of irrigation scheduling to self-propelled irrigations systems requires a method of estimating the diurnal canopy temperature dynamics using only a one-time-of-day measurement. Other research efforts such as the crop water stress index (CWSI) and field canopy temperature mapping using moving irrigation systems could also be served by the use of this method. This was accomplished using a stationary reference measurement to capture the canopy temperature dynamics. Two different methods were developed for estimating a temperature curve for a remote location from a one-time-of-day measurement at that location. The first method (scaled method) uses the ratio between the reference temperature and the remote location temperature, referenced to the predawn temperature, to scale the reference curve to yield the predicted curve. In the second method (Gaussian difference method), a three-parameter Gaussian equation was empirically fitted to the temperature differences between the reference and the measured remote canopy temperature curves. To test these two methods, canopy temperature data, sensed using stationary infrared thermometers, from three different crops {corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), and soybean [*Glycine max* (L.) Merr.]} were analyzed. For a few hours after dawn and before sunset, the scaled method was generally more accurate while during the middle of the day, the Gaussian difference method was more accurate. The average absolute value of the error between the predicted and actual temperatures from the best of both methods during daylight hours was roughly 0.5°C. For all 3 yr, the total irrigation for a season using the extrapolated temperatures were within 18 mm on average of those actually scheduled using the TTT method and measured data.

AN AUTOMATED IRRIGATION scheduling and control system that responds to stress indicators from the crop itself has the potential to lower crop management and labor requirements and to increase yields per unit of irrigation water. Burke (1993) and Burke and Oliver (1993) showed that plant enzymes operate most efficiently in a narrow temperature range termed the thermal kinetic window. Wanjura et al. (1992, 1995) demonstrated that the use of this window as a canopy temperature threshold could be used as a criterion for simplifying and automating irrigation scheduling. Upchurch et al. (1996) received U.S. patent no. 5539,637 for an irrigation management system termed the temperature–time threshold (TTT) method of irrigation scheduling. If the crop-dependent threshold temperature is exceeded for the

climate-dependent threshold time, then an irrigation event of a fixed depth is scheduled (Fig. 1). Evett et al. (1996, 2000) demonstrated in drip-irrigated plots that automatic irrigation using the TTT method was more responsive to plant stress and showed the potential to outyield manual irrigation scheduling based on a 100% replenishment of crop water use as determined by neutron probe soil water content measurements. It is desirable to apply the TTT method to moving irrigation systems such as center pivots or linear-move systems. However, infrared thermometers (IRTs) mounted on moving irrigation systems provide only one-time-of-day measurements. This necessitates a method of estimating the diurnal canopy temperature dynamics using only a one-time-of-day canopy temperature measurement.

Other canopy temperature-based crop stress indicators such as the Crop Water Stress Index (CWSI; Jackson, 1982) are sensitive to the time of day that the measurements are taken (U.S. Water Conserv. Lab., 2004). There is also an increased interest in quantifying spatially varying crop response to soil-, water-, disease-, or pest-induced stresses using IRTs mounted on moving irrigation platforms (e.g., Sadler et al., 2002; Evans et al., 2001). This may be especially important for use with precision irrigation applications. Since these self-propelled irrigation systems move slowly, it often requires many hours to measure the canopy temperatures in the whole field, and the collected temperature maps must be adjusted for time-of-day temperature differences. A valid method of determining the canopy temperature at a remote location at times other than when the measurement was taken would serve both of these research efforts.

Several different models exist that can predict the dynamics of the crop canopy temperature as part of a soil–plant–atmosphere energy balance (e.g., Evett and Lascano, 1993). However, these models require as input detailed weather data and knowledge of soil- and plant-specific parameters that are neither readily available nor easy to measure. The most direct and simple way to determine how changing environmental conditions over a day affect canopy temperature dynamics is to measure canopy temperature dynamics in one stationary reference location. We hypothesized that canopy temperatures in other parts of a field may be modeled relative to this reference using one-time-of-day temperature measurements from those locations. Two different

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Published in Agron. J. 96:1553–1561 (2004).
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Abbreviations: CWSI, crop water stress index; DOY, day of year; IRT, infrared thermometer; IRTC, infrared thermocouple; TTT, temperature–time threshold.

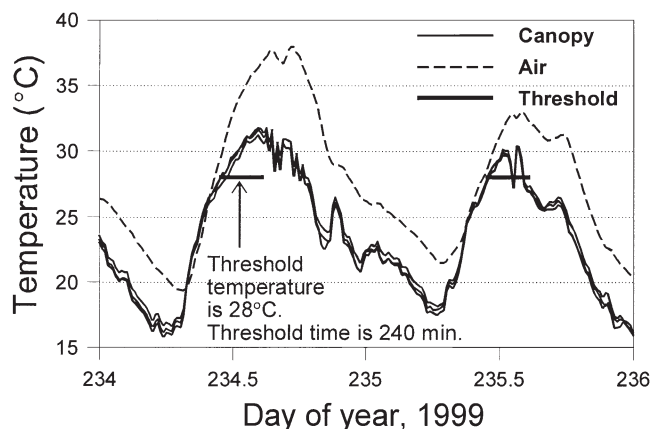


Fig. 1. Canopy temperatures of three replicate plots of the 28°C, 240-min treatment on corn in 1999 compared with air temperature. Also shown are horizontal bars drawn at the threshold temperature of 28°C and over the length of the threshold time. Because the canopy was above the threshold temperature for more than the threshold time on Day 234, irrigation occurred in the evening of that day but not in the evening of Day 235.

methods for doing this were developed and tested, called here the scaled method and the Gaussian difference method.

Evelt et al. (1994) reported a scaling method for soil surface temperature that relied on measurements of soil surface temperature at a reference location (T_{ref}) taken at 15-min intervals throughout the day with thermistors and that used two surface temperatures measured with an IRT at a remote location to estimate the 15-min surface temperatures at the remote location (T_{rmt}). The scaling equation was

$$T_{rmt} = b_0 + b_1 T_{ref} \quad [1]$$

where

$$b_1 = (T_{rmt \max} - T_{rmt \min}) / (T_{ref \max} - T_{ref \min}) \quad [2]$$

$$b_0 = T_{rmt \min} - b_1 T_{ref \min} \quad [3]$$

and where $T_{rmt \max}$ and $T_{rmt \min}$ were the maximum and minimum surface temperatures at the remote location measured by IRT, respectively, and $T_{ref \max}$ and $T_{ref \min}$ were the maximum and minimum reference surface temperatures measured by thermistors. Regressions of measured vs. estimated temperatures resulted in r^2 values > 0.99 for 8 d. However, slopes and intercepts were not always unity and zero, respectively, usually because of discrepancies between surface temperature measurements by IRT and thermistor. In the same study, temperature minimum values, which occurred predawn, were nearly identical at all locations when measured by IRT (Evelt, 1989, p. 86). This indicates that Eq. [1] to [3] might be considerably simplified if all temperatures were measured using the same method. That is, it might be possible to assume that $T_{rmt \min} = T_{ref \min}$ so that only a measure of $T_{rmt \max}$ would be needed at the remote location. Also in the same study, it was found that $T_{rmt \max}$ and $T_{ref \max}$ need not be the actual maximum temperatures so long as they were measured at the same time and within 1 or 2 h of solar noon. It was not determined how distant

in time from solar noon these measurements could be taken and still have the scaling method work well.

Objectives of this study were (i) to determine if minimum (predawn) canopy temperatures measured by IRT are practically equal for different irrigation treatments, allowing simplification of the method of Evelt (1989) for scaling of canopy temperatures; (ii) to examine the accuracy of the scaling method and its effectiveness for TTT irrigation scheduling compared with scheduling based on actual canopy temperature measurements; (iii) to determine the accuracy of the scaling method as affected by the time of measurement of $T_{rmt \max}$ and $T_{ref \max}$; and (iv) to examine, in the same way, an alternative scaling method based on a Gaussian equation fit to the differences in temperature.

MATERIALS AND METHODS

Data from 3 yr (1999, 2001, and 2002), each with a different crop (corn, cotton, and soybean, respectively), were utilized from the drip irrigation studies done on the TTT method by Evelt et al. (1996, 2000) from 1996 through 2002 at Bushland, TX (35°11' N, 102°06' W; 1170 m elevation above mean sea level). During the prior studies, two different canopy temperature thresholds were used with two different time thresholds to create four automatic irrigation treatments as shown in Table 1. Treatment plots were triply replicated, resulting in 12 sets of canopy temperature data. Threshold temperatures and times were determined as explained in Evelt et al. (1996, 2000) to result in a range of well-watered to stressed conditions. Agronomic practices common in the region for high yield were applied.

Canopy temperature was measured with stationary infrared thermocouples (IRTcs; model IRT/c.2-T-80, Exergen Corp.,¹ Watertown, MA) digitized with a data logger (model 21X, Campbell Scientific, Inc., Logan, UT) that also served to control flow to the 12 plots irrigated by canopy temperature control. The IRTcs were tested using a black body over a temperature range similar to that expected (and measured) in the field. The IRTC-measured temperatures were very close to the black body temperature at the middle of the temperature range (25°C), which was the match point for factory calibration and which was close to the threshold temperatures, so no individual calibrations were used. Corrections for reflected

¹ The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA-ARS.

Table 1. Summary of the treatments used for each year and crop.

Year	Crop	Thresholds		Relative irrigation
		Temp.	Time	
		°C	min	
1999	corn	28	240	mid†
		28	160	most
		30	160	mid†
		30	240	least
2001	cotton	28	452	mid†
		28	288	most
		30	288	mid†
		30	452	least
2002	soybean	27	256	mid†
		27	171	most
		29	171	mid†
		29	256	least

† Theoretical irrigation to meet crop needs as described in Evelt et al. (1996, 2000).

longwave radiation were not applied. In the expected long-wave reflectance intensities (300 to 450 W/m²) and leaf emissivities (0.96 to 0.98), the errors from reflected IRTCs would be less than 1°C. One IRTC was allocated per plot, mounted on an adjustable mast one-third of the distance from the south end of the plot and adjusted to point down 45° from the horizontal and to point across the rows at 45° from north toward the east. The measurement starting dates and IRTC heights above the canopy were chosen so that soil was not viewed by the IRTC. Canopy temperature data were recorded in 1999 when the plots were planted to corn from day of year (DOY) 180 to 256. Canopy temperatures were recorded for cotton in 2001 from DOY 186 to 269 and for soybean in 2002 from DOY 222 to 276. Each irrigation was 10 mm, which was equivalent to the crop's peak daily evapotranspiration rate.

Scaled Method

If predawn canopy temperatures (T_e) throughout the whole field (Fig. 2) are assumed to be the same (i.e., $T_{\text{rmt, min}} = T_{\text{ref, min}} = T_e$), and instead of the daily maximum and minimum temperatures being used for scaling, the remote one-time-of-day temperature measurement at any daylight time t ($T_{\text{rmt},t}$) and the measured reference temperature ($T_{\text{ref},t}$) are used, then Eq. [1] through [3] simplify to:

$$T_{\text{rmt}} = T_e + \frac{(T_{\text{rmt},t} - T_e)(T_{\text{ref}} - T_e)}{T_{\text{ref},t} - T_e} \quad [4]$$

where T_{ref} , the reference temperature at every other time during the day, is used to predict the temperature at that same time (T_{rmt}) at the remote location (all temperatures in °C) (Fig. 2).

Gaussian Difference Method

An alternative method was developed and tested that approximates the diurnal canopy temperature curve from a one-

time-of-day measurement and a reference diurnal temperature curve. The difference between two canopy temperature curves over the course of a day tends to follow a general form that can be estimated using a three-parameter Gaussian equation as:

$$T_d = Ae^{\left[-0.5\left(\frac{t-t_p}{w}\right)^2\right]} \quad [5]$$

where T_d is the predicted temperature difference ($T_{\text{rmt},t} - T_{\text{ref},t}$) from the reference (°C) at time of day t (h), A is the amplitude of the peak (°C), t_p is the hour of day (h) of the peak, and w is a factor that predicts the width of the peak (h).

The least squared error method was used to fit Eq. [5] to a large number of diurnal canopy temperatures differences using various treatments as reference temperatures to find constant values of t_p and of w while allowing A to vary. Since the scale of the difference was of highest concern, the results of the fitted t_p and w were weighted by the magnitude of the amplitude difference, A . To use Eq. [5] to predict canopy temperature at a remote location, the measured time (t) and the canopy temperature difference (T_d) were used in Eq. [5] to solve for A . Once A was known, the remainder of the points in the diurnal canopy temperature curve were calculated by computing the temperature difference at each point using Eq. [5] and adding that difference to the reference temperature value.

Other Data Analysis

The averages of the three replicates of canopy temperature measurement for each irrigation treatment at all daylight times (0600–2200 h CST) and days when data were collected were regressed against each other to determine if the dynamics of temperature over the day were the same for all treatments. This would be true if the coefficient of determination were nearly unity, indicating a straight line fit and equivalent dynamics for different treatments.

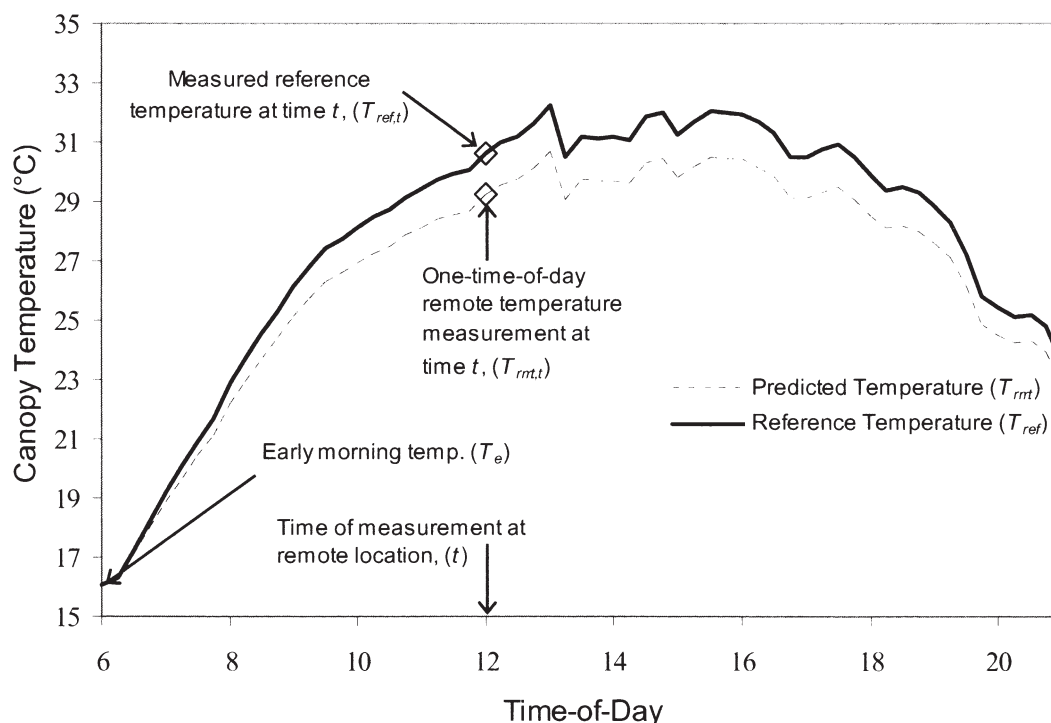


Fig. 2. Diagram of the terms used in the scaled method (Eq. [4]). Time t might be any daylight time at which a canopy temperature ($T_{\text{rmt},t}$) was measured at a remote location in the field. A contemporaneous temperature ($T_{\text{ref},t}$) from the reference temperature data is then used in Eq. [4] along with the common predawn minimum temperature (T_e) and each value in the reference temperature data (T_{ref}) to predict corresponding temperatures at the remote location throughout the daylight hours (T_{rmt}).

Table 2. Linear correlations between treatment mean canopy temperatures for corn (5005 observations), cotton (5512 observations), and soybean crops (3641 observations) and for four irrigation scheduling treatments using the temperature–time threshold method.

		Relative irrigation			
Treatment†	Relative irrigation	Mid‡	Most	Mid‡	Least
1999 Corn					
		Treatment†			
		28/240	28/160	30/160	30/240
28/240	Mid‡	1			
28/160	Most	0.9976	1		
30/160	Mid‡	0.9943	0.9951	1	
30/240	Least	0.9894	0.9883	0.9965	1
2001 Cotton					
		Treatment			
		28/452	28/288	30/288	30/452
28/452	Mid‡	1			
28/288	Most	0.9904	1		
30/288	Mid‡	0.9913	0.9838	1	
30/452	Least	0.9798	0.9614	0.9865	1
2002 Soybean					
		Treatment			
		27/256	27/171	29/171	29/256
27/256	Mid‡	1			
27/171	Most	0.9984	1		
29/171	Mid‡	0.9936	0.9914	1	
29/256	Least	0.9939	0.9916	0.9987	1

† The first number in each treatment code is the threshold temperature; the second number is the threshold time. For example, the code 28/240 indicates a 28°C threshold temperature and a 240-min threshold time.

‡ Theoretical irrigation to meet crop needs as described in Evett et al. (1996, 2000).

To determine if minimum canopy temperatures were equal despite irrigation treatment and plot location, all data (12 data sets for each year) were used in a repeated measures analysis of the effect of irrigation treatment on predawn minimum canopy temperatures for each crop (PROC MIXED, Littell et al., 1996). Three covariance structures were tested: a compound symmetric, an autoregressive order 1, and an unstructured covariance.

The average of the three replications of one of the irrigation treatments was chosen indiscriminately as the reference canopy temperature for both scaling methods. The scaled and the Gaussian difference methods were used to predict the diurnal canopy temperature curve using the measured temperature at each time increment from 0600 to 2200 h CST in 15-min intervals. This resulted in 65 predictions of the diurnal canopy temperature curve for each of the nine other plots for each day. The mean absolute error between the predicted and actual temperature over the whole day was determined for each. This was done for every day that canopy temperature data were collected during the respective year.

The predicted diurnal temperature curves for each irriga-

Table 3. Repeated measures analysis of the effect of irrigation treatment and day of the year on predawn minimum crop canopy temperature.

Effect	Crop		
	Corn	Cotton	Soybean
Irrigation treatment	$P > F$	$P > F$	$P > F$
Day of year	0.3417	0.2663	0.6081
Treatment × day interaction	<0.0001	<0.0001	<0.0001
	0.5893	0.9978	0.0221

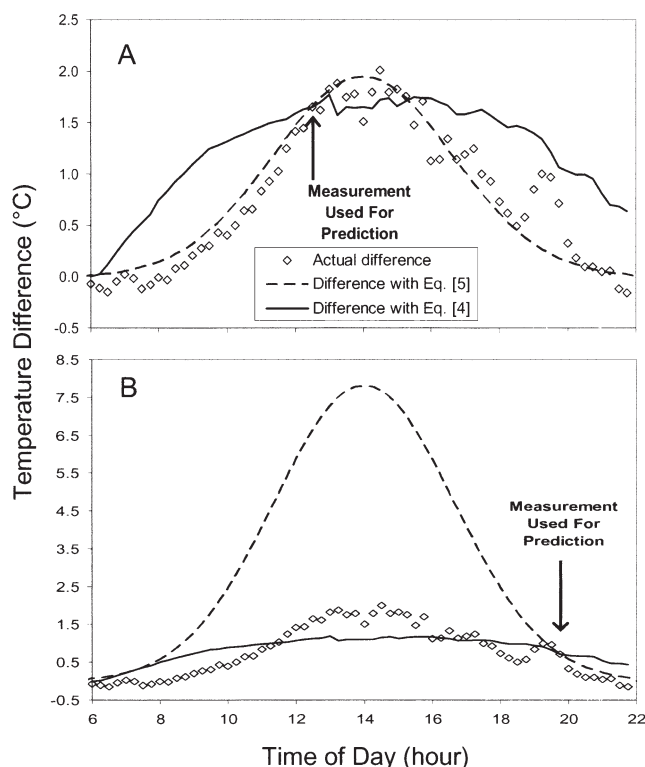


Fig. 3. Example differences between the reference canopy temperature and the predicted canopy temperatures for both the Gaussian difference method (Eq. [5]) and the scaled method (Eq. [4]). Data are from 1999 corn, Day of Year 205 using the mean temperature of the 30/240 treatment as the reference temperature, $T_{ref,r}$. In (A), the temperature at 1230 h CST from the 28/160 treatment was used for the value of $T_{rmt,r}$ in Eq. [4]; and the mean temperature of the 30/240 treatment at the same time was used for the value of $T_{ref,r}$. The value of T_d in Eq. [5] at 1230 h CST was set equal to $T_{rmt,r} - T_{ref,r}$. In (B), the time for evaluation of $T_{rmt,r}$ and $T_{ref,r}$ was 1945 h CST. In both (A) and (B), the actual difference in canopy temperature between the 28/160 treatment and the mean temperature for the 30/240 treatment is shown for comparison.

tion treatment were used to calculate whether an irrigation would be required during that day using the TTT method and threshold times and temperatures for each treatment. The timing and irrigation signals were compared using the original canopy temperature data and using the predicted data.

RESULTS AND DISCUSSION

Linear correlations amongst diurnal canopy temperatures for all irrigation treatments showed that canopy temperatures were linearly related to a great degree despite differences in irrigation treatment (Table 2). This supports the assumption of linearity inherent in the scaling Eq. [1] through [4]. Among all of the various irrigation treatments and crops, the lowest obtained r^2 value was 0.96 for regression of the average temperature of the 28/288 treatment vs. that of the 30/452 treatment for cotton in 2001. The average of all the other r^2 values was 0.99. This shows a strong linearity between the dynamics in one treatment and the dynamics in another and supports use of the scaling method.

Repeated measures analysis with an autoregressive covariance structure gave the best fit to predawn temperature data for all three crops. The irrigation treat-

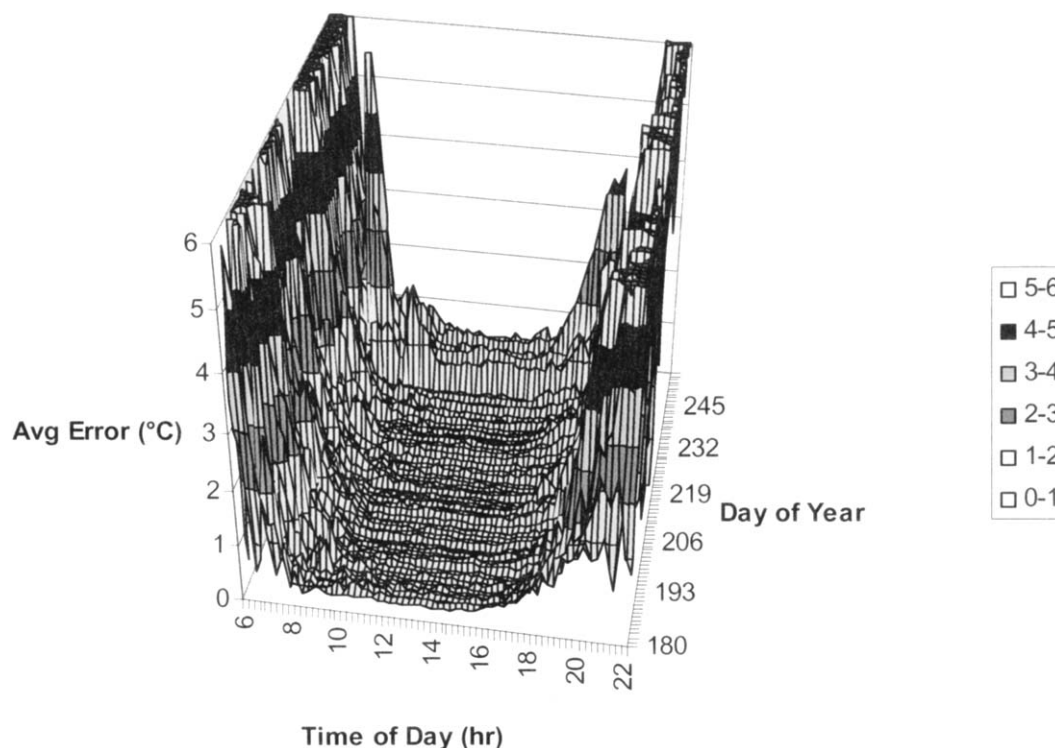


Fig. 4. The mean absolute error between predicted (Eq. [5]) and measured temperatures using the temperature measurement for all times of day for each day of the year that canopy temperatures were measured. Values are shown for the 28/240 treatment for corn in 1999. The mean temperature of the 28/160 treatment was used as the reference.

ment effect was not significant in this analysis for any of the crops, indicating that predawn temperatures were practically equal for all of the irrigation treatments (Table 3). This means that the assumption of equal predawn temperatures for any location in a field is a good one. Day of the year did have a significant effect, and for the soybean crop, the interaction between treatment and DOY was significant. This latter was most likely caused by the inclusion of days during senescence of the soybean crop. The results indicate that, for all three crops, we can safely assume that $T_{\text{ref min}} = T_{\text{rnt min}}$ in Eq. [1] to [3] so that only a single measure of canopy temperature is needed at the remote location to scale a reference diurnal canopy temperature curve to a curve representative of the remote location, making Eq. [4] valid. Therefore, at night, the closest approximation to canopy temperature may simply be the reference temperature.

Equation [5] was empirically fitted (using the least squared error method) to the 1999 corn crop data from each 15-min interval from 0600 to 2200 h CST for each day that data were collected. The average values of $t_p = 14$ h and $w = 2.63$ h were found. These were then tested against the soybean and cotton crops, which have much different leaf shapes and growth characteristics, and were found to also fit well. Because this equation uses actual times of day, the value chosen for t_p depends on the site longitude in reference to time zone demarcation lines (i.e., solar noon occurs at slightly different times).

Figure 3 exemplifies some of the differences between the two methods used to predict a diurnal canopy temperature curve from a one-time-of-day measurement.

Plotted here are the temperature differences between the reference temperature and the remotely located canopy temperature, the latter either measured or predicted using Eq. [4] and [5]. Figure 3A shows both the measured actual difference between the remote and reference temperature and also the predicted temperature difference with both the scaled and the Gaussian difference methods using a 1230 h CST remote canopy temperature measurement. Figure 3B shows the same information using a 1945 h CST canopy temperature measurement. The difference from the reference temperature calculated using the scaled method was not smooth like that of the Gaussian difference method. The shape of the difference calculated using Eq. [5] more nearly approximated the shape of the plotted actual difference data. However, the errors increase drastically at times far from solar noon.

Canopy temperatures were predicted for each quarter-hour interval of each day for all three crops, using one-time-of-day measurements from each quarter-hour datum (65 sets of predictions of quarter-hourly canopy temperatures throughout the day for each day). The mean absolute error between predicted and measured temperatures using the one-time-of-day canopy temperature measurement for all times of day was calculated across all the days of the season. For a short time after sunrise and before sunset, errors using Eq. [5] were large as exemplified by Fig. 4 for the 28°C, 240-min treatment for corn. Early-morning and late-afternoon errors were somewhat smaller using Eq. [4] (graph not shown). These average error values showed a slight change over the season in the time of morning that the

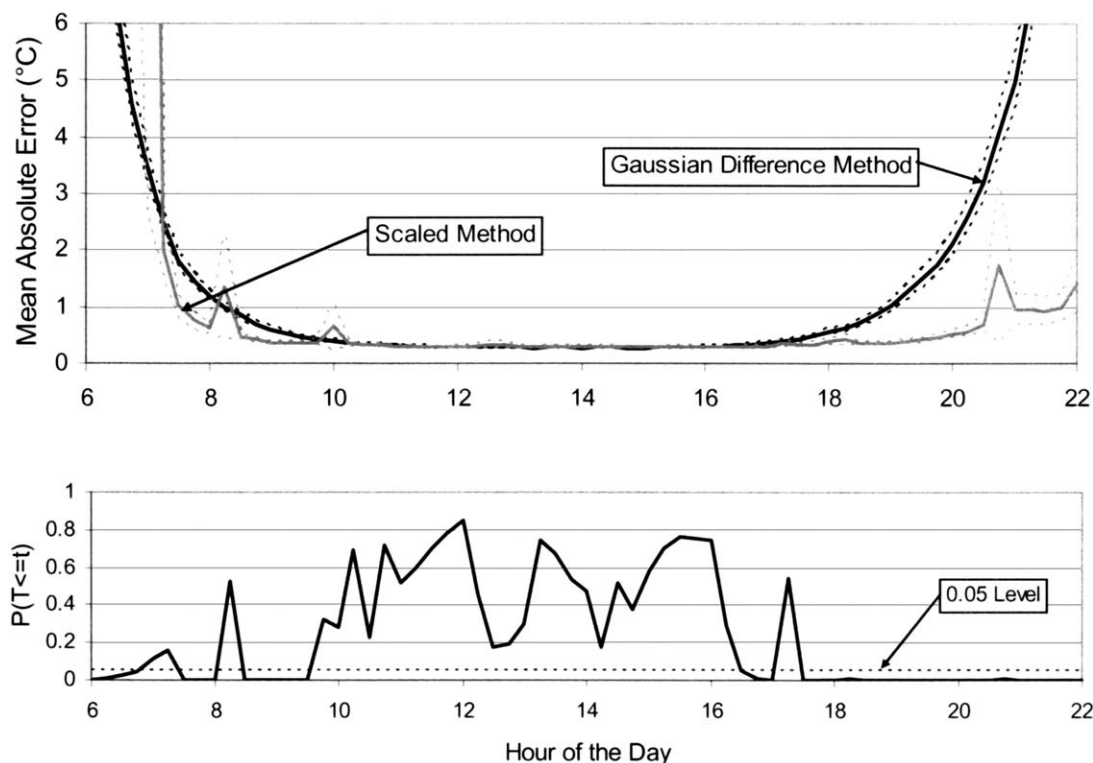


Fig. 5. Comparison between the two methods of the overall mean error across treatments for corn in 1999 showing 95% confidence limits for each. Also shown is the probability that the differences between the two methods are due to variation, denoted $P(T \leq t)$, using the students t test at each point. The mean temperature of the 28/160 treatment was used as the reference.

errors were large, probably due to daylength changes and crop senescence. Because most time above the threshold temperature is accumulated from 1000 h CST on-

ward (e.g., Fig. 1), and because errors after that time do not become large until well after most time thresholds have been crossed, either method should provide

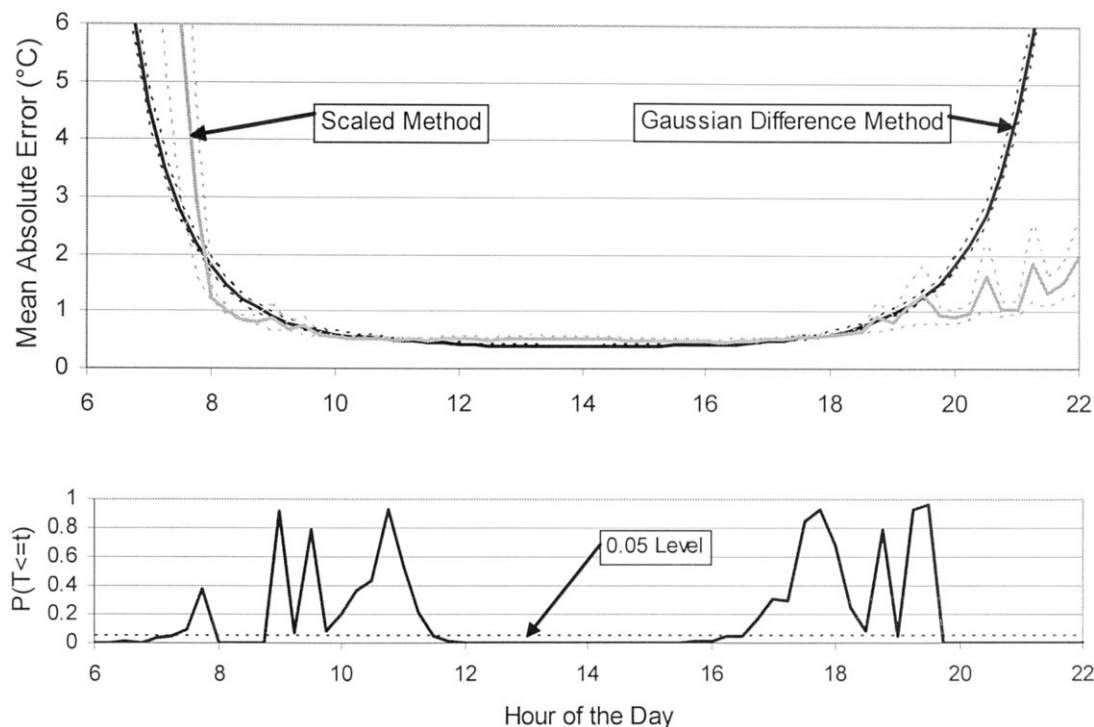


Fig. 6. Comparison between the two methods of the overall mean error across treatments for cotton in 2001, showing 95% confidence limits for each. Also shown is the probability that the differences between the two methods are due to variation, denoted $P(T \leq t)$, using the students t test at each point. The 30/452 treatment mean temperature was used as the reference.

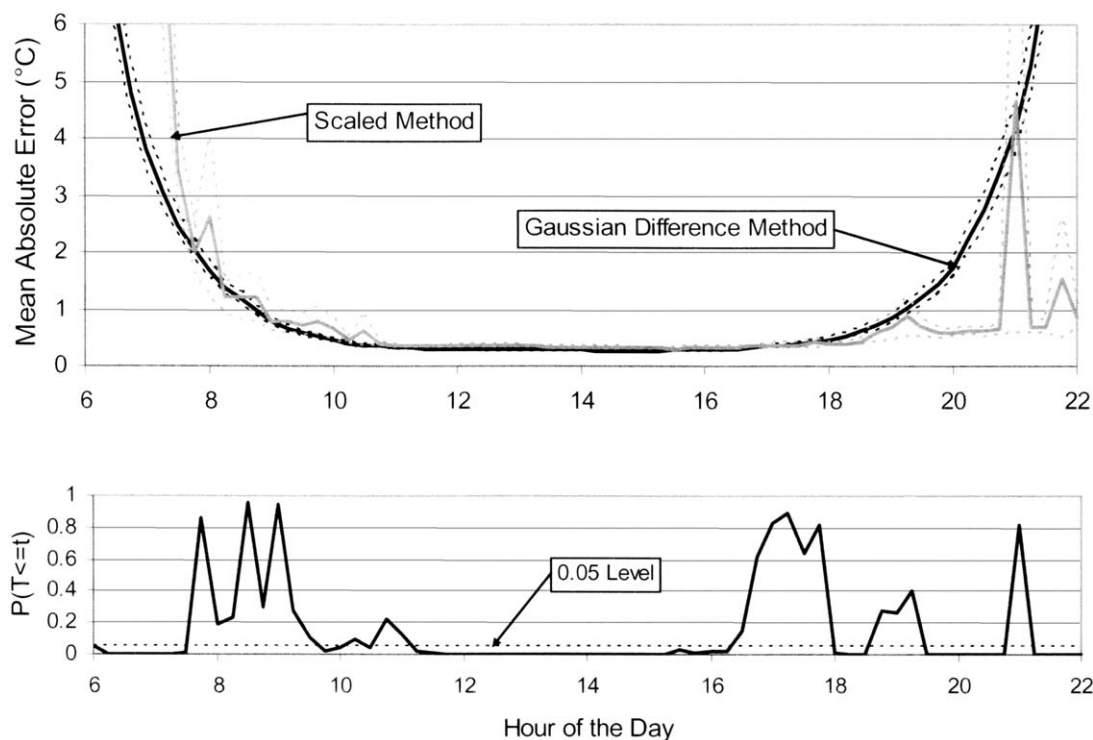


Fig. 7. Comparison between the two methods of the overall mean error across treatments for soybean in 2002, showing 95% confidence limits for each. Also shown is the probability that the differences between the two methods are due to variation, denoted $P(T \leq t)$, using the students t test at each point. The 27/171 treatment mean was used as the reference.

useful temperature predictions for the TTT irrigation-scheduling method for the three crops in question.

In general, errors using Eq. [4] were smaller than

those using Eq. [5] at the beginning and end of the day, meaning that one-time-of-day temperature measurements obtained soon after sunrise or close to sunset

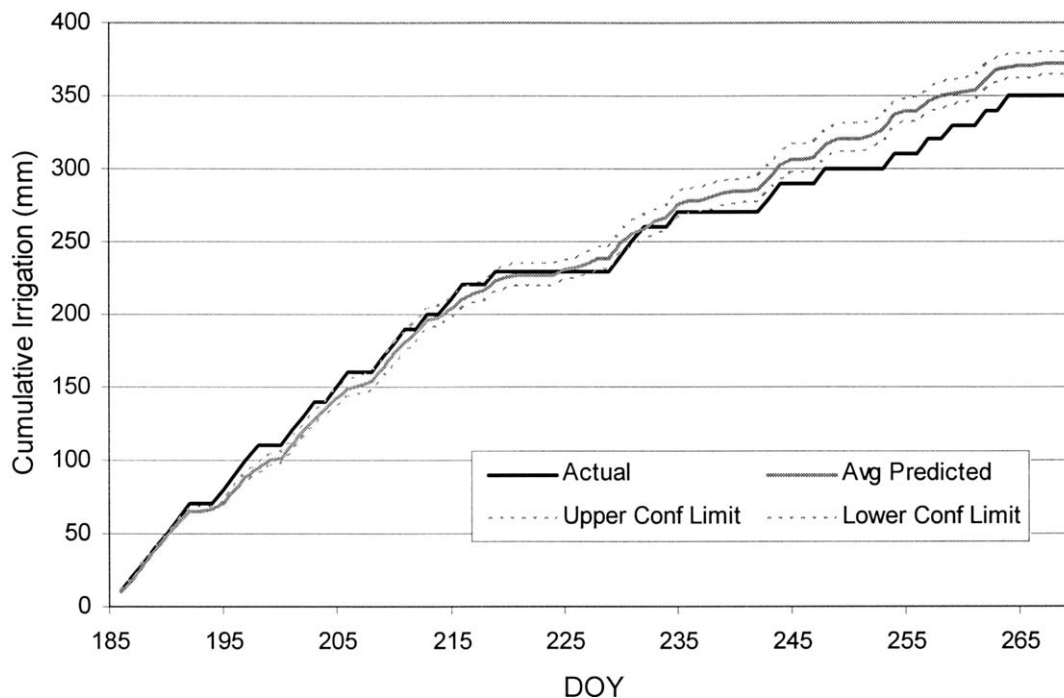


Fig. 8. Comparison of the cumulative number of irrigations calculated using the temperature-time threshold (TTT) method and the field-measured canopy temperature data compared with the average of the cumulative irrigation signals calculated using temperatures predicted by the scaled method. The data shown for the scaled method are averages using one-time-of-day temperature measurements at all times from 0815 to 2200 h CST. The 95% confidence limits are drawn around the average predicted cumulative number of irrigations. Data are from the 2001 cotton crop and the 28/452 treatment.

Table 4. Difference of the predicted from the actual cumulative irrigation curves (mm) (cumulative actual irrigation minus cumulative of the average predicted irrigation).

Year	Crop	Irrigation treatment†	Eq. [4]		Eq. [5]		Eq. [4] and [5] combined	
			EOY‡	Max§	EOY	Max	EOY	Max
1999	Corn	28/240	6	9	40	40	27	28
		28/160	–14	–15	–15	–16	–16	–17
		30/240	–14	–14	1	8	–12	–12
		30/160	–30	–30	–14	–15	–26	–26
2001	Cotton	28/452	–22	–30	–27	–36	–21	–28
		28/288	–24	–24	–11	–13	–26	–26
		30/452	–48	–48	17	21	11	15
		30/288	26	26	23	23	29	32
2002	Soybean	27/256	8	–9	4	–6	9	–9
		27/171	–17	–17	–13	–13	–25	–25
		29/256	–6	–14	–2	–8	–5	–11
		29/171	11	14	2	3	9	10

† The first number in each treatment code is the threshold temperature; the second number is the threshold time. For example, the code 28/240 indicates a 28°C threshold temperature and a 240-min threshold time (Evelt et al., 1996, 2000).

‡ EOY, end of year difference.

§ Max, maximum difference throughout the season.

are more likely to result in relatively accurate diurnal temperature prediction if Eq. [4] is used. In the middle of the day, differences in the errors for the two methods were small. There was relatively little difference in error rate across irrigation treatments. Plots not shown for the soybean and cotton crops showed similar results.

For temperature predictions using both methods, the mean error and the 95% confidence limits for the mean for each 15-min time interval were calculated for all days in each season (Fig. 5–7) (means include all treatments). The probability that the difference between the means of error values from either method is due to variability (calculated using the students *t* test) is also given for each time period. As expected, this probability increased where the curves converged or crossed. These results show that the Gaussian difference method was significantly more accurate than the scaled method during the middle of the day for cotton and soybean but was not significantly different for corn. Although the differences between the two methods during the middle of the day were significant for cotton and soybean, these differences were not generally important as the greatest differences were less than 0.15°C. The scaled method tended to be better at making predictions early in the day or late in the evening (Fig. 5–7). The Gaussian difference method was much more prone to error in the early and late hours of the day. From the best of both methods, the mean absolute error between the predicted and actual temperatures was roughly 0.5°C.

Irrigations scheduled using the TTT irrigation-scheduling method and the field-measured temperature data were compared with irrigations scheduled using the TTT method and diurnal canopy temperature curves predicted by each method (Eq. [4] and [5]) from one-time-of-day measurements taken from 0600 to 2200 h CST. For example, the cumulative irrigation received using the actual canopy temperature measurements was 22 mm less than the average of the cumulative predicted irrigation amounts across all times of day for each day using the scaled method to predict the diurnal canopy temperature curves for cotton (Fig. 8). This is equivalent to about 7% of the total irrigation and 3% of the total crop water use. As predicted using the scaled method,

the magnitude of the maximum departure of the cumulative irrigation curve from the actual cumulative irrigation curve in Fig. 8 was 30 mm on DOY 256. These same statistics were calculated for every crop and treatment (Table 4). Also included are statistics for a combination of the two methods in which the scaled method was used to predict the diurnal canopy temperature curve from all times from 0815 to 0945 h CST and again from 1800 to 2200 h CST, and the Gaussian difference method was used at all times from 1000 to 1745 h CST. The maximum end-of-year difference was an average of 48 mm for the 30/452 treatment for cotton using the scaled method. However, the mean of the end-of-year differences between actual and average predicted irrigations was 18 mm.

CONCLUSIONS

Both the scaled method (Eq. [4]) and the Gaussian difference method (Eq. [5]) are viable methods for predicting the diurnal canopy temperature dynamics from a one-time-of-day measurement using a reference temperature during daylight hours. Both of these methods were tested against three different crops and found to be fairly crop independent. The Gaussian difference method is somewhat more accurate during the middle of the day but less accurate than the scaled method near sunrise and sunset. It also requires fitting of t_p and w for local conditions. The scaled method is likely the most applicable to most situations. These methods will aid in the application of the TTT method of irrigation scheduling to self-propelled irrigation systems as well as the CWSI and canopy temperature mapping for precision irrigation information.

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